

Feature Extraction and Manufacturability Assessment of Sheet Metal Parts

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1 Introduction

Feature recognition or feature extraction of sheet metal parts is a necessary and important activity to support the design and manufacturing automation. The term feature recognition refers to techniques that are able to automatically identify design features of part from its drawing file. Figure 1 depicts some features of a typical sheet metal part. Various features of sheet metal parts mainly categorized into three groups, i.e., shearing features, bending features, and deep drawing features as shown in Fig. 2. There are two methods for feature extraction (i) Constructive solid geometry (CSG), and (ii) Boundary representation (B-rep) (Srinivasakumar et al. 1992). The CSG of the solid model is specified with a set of Boolean operations and a set of 3-D solid primitives. On the other hand, the B-rep of a solid model contains information about faces, edges, and vertices of a surface model and at the same time

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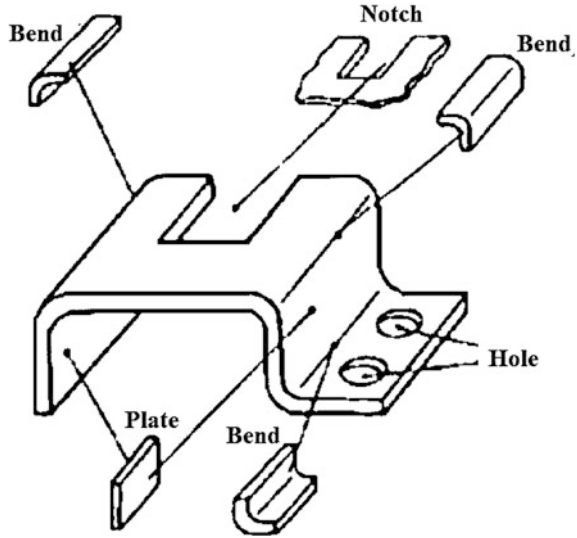
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Fig. 1 Design features of a typical sheet metal part (Wierda 1991)



includes topological information that defines the relationship between the faces, edges, and vertices. There are three types of model geometry representations used in CAD software (Subrahmanyam and Wozny 1995)—wireframe model, surface model, and solid model. Wireframe models are composed of points and curves that represent the edge boundaries of product geometry. Complex part geometry is seldom created in wireframe model. However, it is easily and automatically generated by neutral file transfer protocols like IGES and STEP. It is computationally easy to handle when compared to equivalently complex solid models. However, this can be quite ambiguous in regard to what is ‘solid’ and what is not, requiring human intervention for interpretation of geometry. This ambiguity has traditionally been too complex to handle with automated feature recognition systems. Feature recognition using wireframe models has been explored in the past; however contemporary work has shifted to surface and solid models for reasons of model ambiguity (Shah and Mantyla 1995). Solid models are of two types, the constructive solid geometry (CSG) and boundary representation (B-Rep). CSG models are stored in unevaluated or implicit form, and the final part must be calculated from set theory carried out on solid primitives. B-Rep is an explicit representation of the solid boundary including all vertices, faces and edges. One major advantage of CSG feature trees is that the features may be easily arranged by order of construction or destruction; however, CSG is no longer widely used. To automate the die design process, a computer-aided system is required for automatic extraction of design features of sheet metal parts.

Manufacturability assessment of sheet metal parts is another important activity for die design. Traditional process of manufacturability assessment of sheet metal parts involves calculations and decisions, which have to be made on the basis of experience and practice codes without the computer aids. It is estimated that

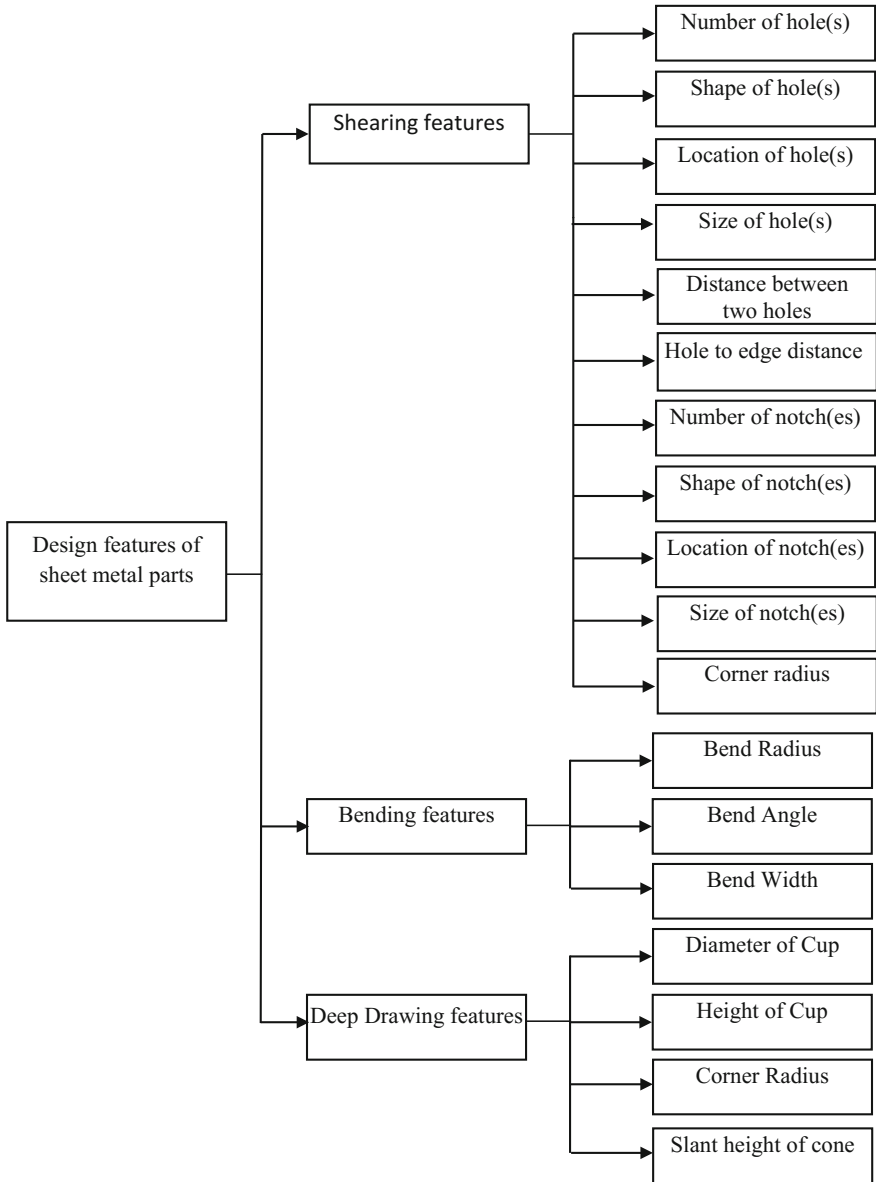


Fig. 2 Common design features of sheet metal parts

decisions made at the part design stage determine 70–80 % of the manufacturing productivity (Makinouchi 1996). Therefore, during the planning for manufacturing of a sheet metal part, it is useful to check its internal as well as external features for assessing its manufacturability on a press tool or die. Such checks are useful to avoid manufacturing defects, section weakness, and need of new dies, tools, or machines. Over the years the industrial practices of checking of the internal and external features of sheet metal parts have not changed significantly.

The present chapter describes a computer-aided system for automatic feature extraction of sheet metal parts and a knowledge-based system (KBS) for manufacturability assessment of sheet metal parts. The chapter is further organized as follows—The first section introduces feature extraction and manufacturability assessment of sheet metal parts. Next, the research efforts applied by worldwide researchers in the area of feature extraction and manufacturability assessment are reviewed. The third section describes a computer-aided system for automatic feature extraction of sheet metal parts. The next section presents a KBS for manufacturability assessment of sheet metal parts. In the fifth section, validation of developed systems of feature extraction and manufacturability assessment has been presented by taking three industrial sheet metal parts. Finally, the present chapter is summarized.

2 Literature Review

2.1 Feature Extraction/Recognition of Sheet Metal Parts

Feature recognition of sheet metal parts was given a new dimension in the late 1980s. Many researchers have worked on feature recognition of sheet metal parts. Meeran and Pratt (1993) developed a system for automatic feature recognition for simple prismatic part. The input is 2-D drawing of prismatic part in a DXF format. Liu et al. (2003) presented a method for automatic extraction of features from arbitrary solid model of sheet metal parts. The developed system is divided into three categories—checking of model geometry, feature matching, and setting feature relationship. Ismail et al. (2005) proposed a new technique for feature recognition from B-rep (Boundary Representation) models. This technique identifies solid and void ‘sides’ of a boundary entity, and extracts cylindrical-based and conical-based features. Emad et al. (2006) proposed an intelligent feature recognition methodology for automatic feature recognition of 3-D prismatic parts. They used solid modeling based on constructive solid geometry (CSG). Zhou et al. (2007) used feature recognition concept for integration of CAD and computer-aided process planning (CAPP). Developed system is capable to recognize features, feature tree reconstruction, technical information processing, and process planning. Sunil and Pande (2008) developed a system for automatic recognition of features from freeform surface CAD models of sheet metal parts represented in STL format.

Rameshbabu and Shunmugam (2009) presented a hybrid approach to recognize the manufacturing features from 3-D CAD model of STEP AP-203. Farsi and Arezoo (2009) described feature recognition model along with the design advisor system for sheet metal parts. They used commercial CAD software and user interface is created using visual basic (VB). Proposed model recognizes part features, such as bend radius, bend angle, length of each bend, bend height, bend direction, bend factor, and sheet thickness. Sunil et al. (2010) developed the new hybrid approach for recognizing the interacting feature from B-rep CAD model. Developed system recognizes all varieties of the simple and stepped holes with flat and conical bottoms from the feature graphs. Wang et al. (2012) proposed a feature recognition system to identify shape and size of different features from 3-D model of part. Tan et al. (2013) developed feature recognition system for integration of CAD and CAM. The CAD model in STEP format is used for recognition of holes on sheet metal part. Rule-based technique is used for development of feature recognition rules. Hussein and Kumar (2008) used STEP AP-203 CAD model for feature recognition of 3-D prismatic parts. The attribute adjacency graph (AAG) and attribute adjacency matrix (AAM) approaches have been used for recognition of assembly features. System can recognize both depression and protrusion features.

From review of available literature it is found that the worldwide researchers have applied efforts to develop computer-aided feature extraction/recognition systems for sheet metal parts. Most of the researchers have developed systems which are able to perform feature recognition only for simple part geometry. Also, most of these CAD systems uses semi-automatic approach and require expert persons to operate the systems and interpret the results. Very few systems have been developed for automatic feature extraction of sheet metal parts. Even these systems are not capable to recognize the complex and intersecting features from solid CAD model. In addition, these systems require high-performance computers for processing of algorithm and extraction of features.

2.2 Manufacturability Assessment of Sheet Metal Parts

Worldwide researchers have applied efforts to develop computer-aided systems for manufacturability assessment of sheet metal parts. For example, Nakahara et al. (1978) introduced a progressive die design system that examines the part design data to decide whether it can be stamped by blanking or not. The Cold Press Die Design and Manufacturing system (CPDDMS) developed by Ying (1986) manipulates the digital representation of blanks stored in data files to perform technology check of the blank geometry. But the main limitation of this system is that it is implemented on a main frame computer with advanced data base support and thus it is beyond the reach of the small and medium sized tool and die industries. Illiev et al. (1989) developed a system, which mainly addresses the technical preparation in the production of flat parts by stamping. The major limitation of this system is that it involves large number of mathematical calculations of the geometrical

characteristics of the sheet metal part just like the traditional methods being used in industries. The Technology Check module of the computer-aided die design system (CADDs) proposed by Prasad and Somasundaram (1992) is capable of assessing the feasibility of sheet metal blank for the blanking process. Lazaro et al. (1993) developed an intelligent system labeled as SMART (Sheet Metal Advisor and Rule Tutor) for identifying design rule violations to improve part manufacturability. System consists of a feature-based CAD system and a knowledge-based system (KBS). Meerkamm (1995) proposed a design support system based on a data exchange format to detect design violations concerning manufacturability of sheet metal, rotational and casting parts, and to advise for correction. Lee et al. (1995) reported an assessment system consisting of knowledge-based geometric analysis module, a finite element module and a formability analysis module. The geometric analysis module uses geometric reasoning and feature recognition with a syntactic approach to extract high-level geometric entity information from vertices in two-dimensional forming. Yeh et al. (1996) developed a rule-based and feature-based design advisor for sheet metal parts called product modeler (ProMod-S), which includes a rule-based design advisor among several other modules. An advisory design rule checker system was proposed by Radhakrishnan et al. (1996). This system is integrated into ProMod-S using medial axis transformation algorithm to check the number of features for complicated sheet metal parts. Wang and Bourne (1997) described a manufacturability-driven decomposition approach to decompose bent sheet metal products into manufacturable parts. Choi and Kim (2001) developed a CAD/CAM system for the blanking or piercing of irregular shaped-sheet metal products for progressive working. The system is capable of checking the production feasibility of parts using AutoLISP and Auto CAD. But this system is limited to stator and rotor parts which require only blanking or piercing operations. Tang et al. (2001) proposed an intelligent feature-based design system for stampability evaluation of a sheet metal part for checking of potential problems in stamping process and stamping die at the design stage itself. Ramana and Rao (2005) developed a system for automated manufacturability evaluation of sheet metal parts. The system describes design evaluation, process planning, data, and knowledge modeling for shearing and bending operations. Scope of the system is limited to simple bending parts only and those parts which can be produced by blanking and piercing operations. Kumar et al. (2006) developed a knowledge-based system (KBS) for checking design features of sheet metal parts to be manufactured on progressive die. Farsi and Arezoo (2009) proposed a system based on object-oriented approach. This system includes two modules: feature recognizer and design for manufacturability module. The system can recognize incorrect features and imparts suggestions for editing incorrect features. Naranje and Kumar (2011) proposed a KBS for manufacturability assessment of deep drawn sheet metal parts. Production rules are coded in AutoLISP language. Graphical user interface is created using Visual Basic (VB) and interfaced with AutoCAD software. Kashid and Kumar (2013) developed a system for manufacturability assessment of parts produced on compound dies.

From the reviewed literature it is found that some researchers have developed specific systems for manufacturability assessment of sheet metal parts using CAD and artificial techniques (AI) techniques. But no system is available to deal with all types of sheet metal parts comprising shearing, bending and deep drawing features.

3 Computer-Aided System for Automatic Feature Extraction

A computer-aided system labeled as FE (*Feature Extraction*) has been developed for automatic feature extraction of sheet metal parts. This system is generic in nature and derives information from the topology, geometry, and Boolean logic. The system has been coded in AutoLISP language. Execution of the proposed system is shown in Fig. 3. Initially, the system invites the user to enter input in form of 3-D CAD drawing of sheet metal part in AutoCAD software. This drawing file is saved as BLKMOD.DWG for its further use. The system extracts design features in two stages—(i) prefeature extraction, and (ii) feature extraction. In prefeature extraction stage, faces of the 3-D CAD drawing file of sheet metal part are exploded. The AutoCAD command ‘EXPLODE’ is used for identifying features present on sheet metal part. In the second stage, features of sheet metal part are extracted automatically by the proposed system. These extracted features are displayed to the user and stored automatically in a data file labeled as FE.DAT. This output data file acts as an input to the subsequent modules of die design automation systems.

4 Knowledge-Based System for Manufacturability Assessment of Sheet Metal Parts

The external and internal design features of the part such as size of blank, width of recesses or slots or projections along blank profile, dimension and location of holes, internal contours, distance of internal features from the edge of blank, draw ratio, bend angle, bend radius, bend width, size and position of hole/slot, and direction of bend should be tested against rules of good practice. Most of the sheet metal industries use internal guidelines for part design based on the experience with the part geometry and materials used in that specific company. While such design guidelines are extremely useful and practical but they do not necessarily consider the fundamental reasons for selecting a given design. Thus, when a new material is introduced the entire set of experienced-based design guidelines must be reevaluated and modified. Therefore, it is necessary to develop generic design guidelines

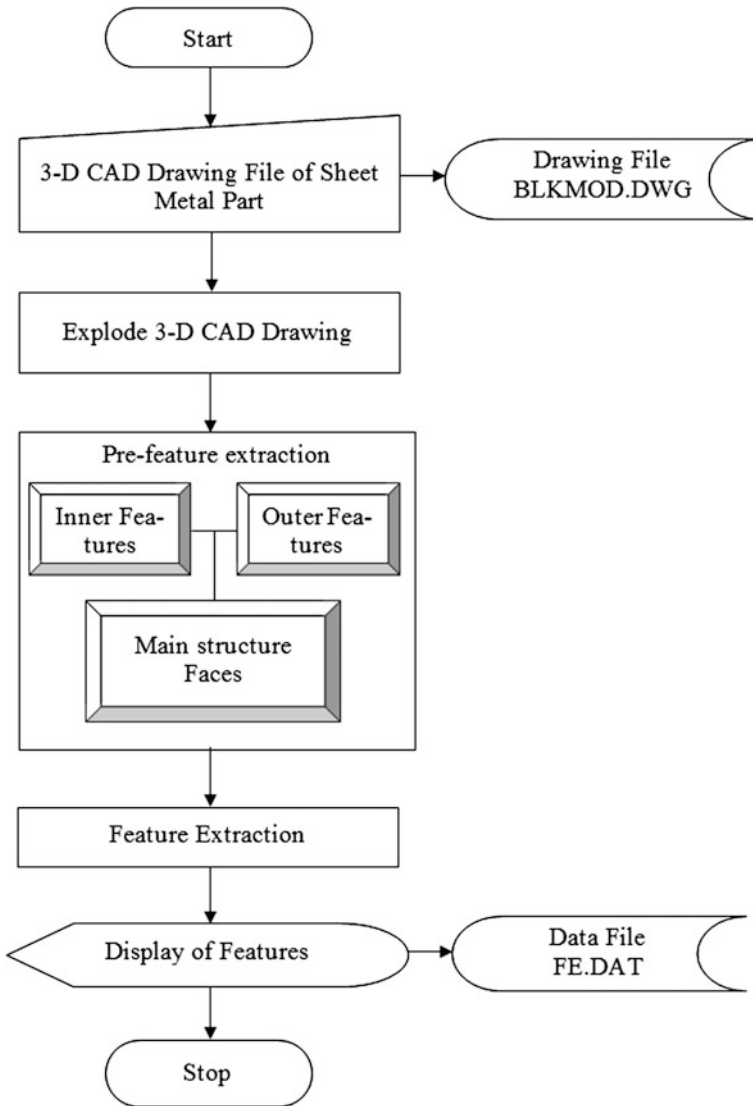


Fig. 3 Execution of FE system

based on metal forming analysis and/or systematic experimental investigation. Figure 4 shows the design guidelines for deep drawn parts used in automotive industries (Suh 1988). Figure 5 shows a sample of design guidelines for bending parts.

Experienced die designers and process planners generally use some basic guidelines to assess manufacturability of sheet metal parts. A sample of these basic

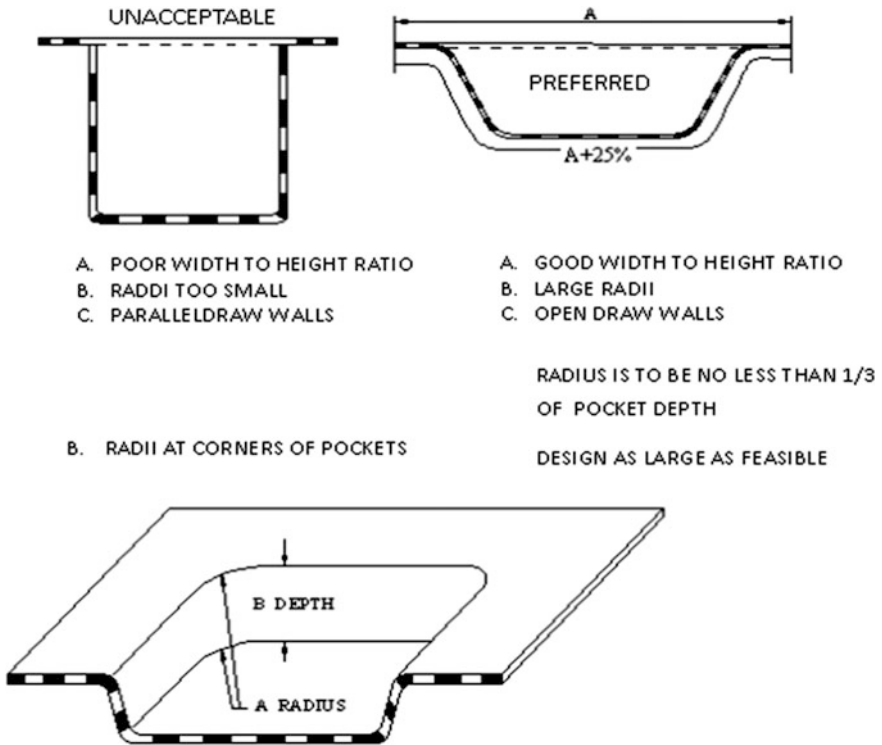


Fig. 4 Design guidelines for sheet metal parts used in automotive industry (Suh 1988)

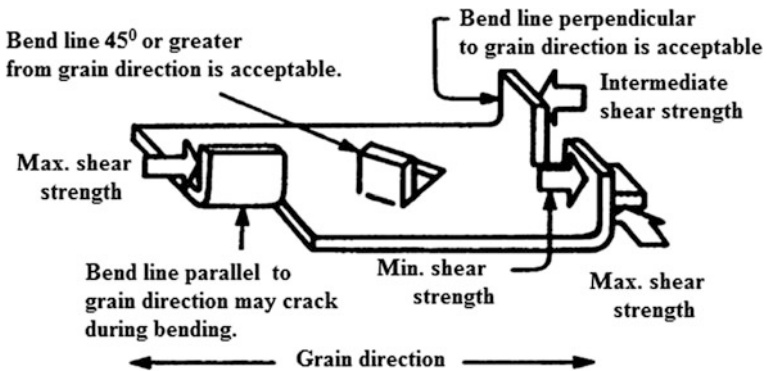


Fig. 5 A sample of design guidelines for bending parts (Farsi and Arezoo 2009)

guidelines is given as under (Kumar et al. 2006; Naranje and Kumar 2011, 2014; Kashid and Kumar 2013):

- (1) The minimum width of sheet metal part is a function of sheet thickness. It is very difficult to design and manufacture dies for long and narrow parts. The width of parts should not be less than 1.5 times of sheet thickness and length should not be greater than five times of width of blank.
- (2) The corner radius on sheet metal parts should be at least 0.7 times of sheet thickness.
- (3) The width of recesses or slots or projections along blank profile should be minimum 1.2 mm.
- (4) The permissible minimum diameter of piercing depends on the type of sheet material, shape of holes and sheet thickness. For piercing round holes, the diameter should not be less than 0.5 mm for hard steel sheet material and 0.4 mm for soft steel, brass or aluminium sheet material. The size of a square or rectangular hole should not be less than 0.35 mm for soft steel, brass, or aluminium sheet material.
- (5) The spacing between holes on sheet metal parts should be at least 2.0 times of sheet thickness.
- (6) The distance between the two nearest internal features influences the ease of manufacturing and the construction of die. The minimum allowable spacing between two internal features depends on the thickness, hardness of sheet material and shape of feature.
- (7) The maximum length of a rectangular/radial notch is generally taken as 5.0 times of width of notch. The maximum length for a 'V'-notch is recommended as 2.0 times of width of notch.
- (8) Scrap web allowance depends on the maximum product size, sheet thickness and shape of product edge.
- (9) Higher thickness to diameter ratio of deep drawn parts is good and it should be at least one percent. If it is less then wrinkling may occur.
- (10) Depth and length of the deep drawn parts must be greater than one half of their diameter.
- (11) Sharp radius (inside radius or flange radius) should be avoided.
- (12) With a large radius of the drawing die ranging between 8 to 15 times of sheet thickness, smaller values of the severity of the draw coefficient may be used. Subsequently, with smaller drawing die radii such as those ranging between 4 to 8 times of sheet thickness, larger draw coefficient is recommended.
- (13) When the draw radius is too small, excessive thinning or fracture results at the bottom of a shell and at any stage of the operation. This can be corrected by increasing die radius or blank diameter to allow easier metal flow.
- (14) Suitability of drawing material should be evaluated on the basis of its coefficient of normal anisotropy.

- (15) Large draw ratios imply long and thin forming punches that tend to be very susceptible to breakage. This increases the maintenance cost of deep drawing die.
- (16) The value of deformation should be within 25–75 % of the value of drawability.
- (17) Vertical axis of blank should be exactly in line with the axis of punch and die during the deep drawing operation.
- (18) For rectangular part, draw depth should be limited to 7 times of corner radius.
- (19) Included corner angle less than 60° reduces feasible depth of draw.
- (20) For rectangular part, both the draw and vertical corner radii must be 5 times of sheet thickness.
- (21) Maximum possible bend angle in a bending part depends on sheet material, sheet thickness, and bend radius.
- (22) The minimum bend radius of a bend depends on sheet material and sheet thickness.
- (23) The bend width should be at least three times of sheet thickness.
- (24) The minimum acceptable bend length of a bend depends on the sheet thickness and bend radius. It should not be less than 2.5 times of sum of sheet thickness and bend radius.
- (25) The bend should be perpendicular to the grain direction or as close as possible in order to avoid fracture of the part.
- (26) The mutually perpendicular bends should be made at 45° to the grain direction.
- (27) The minimum acceptable distance of edge of hole/slot from the nearest edge of bending part depends on sheet thickness and bend radius. It should not be less than 1.5 times of the sum of sheet thickness and bend radius.
- (28) If it is not possible (as per the functional requirement of part) to follow the minimum acceptable distance criteria as mentioned above, then a stress discontinuity should be provided by a nonfunctional hole/slot/tab to prevent the distortion of hole.
- (29) If the hole(s) or slot(s) is/are on a bend line then such feature(s) should be formed after bending.
- (30) Dimensional tolerances less than 0.04 mm is very difficult to maintain and a costly affair.

Keeping in view of the above basic guidelines, a KBS labeled as MCKBS (*Manufacturability Check Knowledge-Based System*) is developed for assessing manufacturability of sheet metal parts at initial stage of design. The system is described as under.

4.1 Procedure for Development of the Proposed System

The procedural steps for the development of the proposed system namely MCKBS include knowledge acquisition, framing and verification of production rules, sequencing of production rules, development of knowledge base, choice of search strategy, and preparation of user interface (Kumar and Singh 2004, 2011; Kumar 2011). Technical knowledge has been acquired from various sources including consultation with experienced die designers, process planners and shop floor engineers, review of published research papers, die design handbooks, industrial brochures, and technical reports. The knowledge thus acquired is analyzed and tabulated in form of production rules of 'IF-THEN' variety. The production rules so framed are verified from a team of domain experts. Production rules are arranged in a structured manner. Suitable software should be selected for development of a knowledge base system As the AutoCAD software has low cost, therefore it can be easily affordable by small scale sheet metal industries. Further, to make user-interactive expert system, visual basic (VB) software is always preferred. The proposed system is implemented using VB and AutoCAD software. To develop knowledge base of the proposed system, production rules are coded in AutoLISP language and graphical user interface (GUI) is created using VB software. The production rules and the knowledge base of the system are linked together by an inference mechanism, which makes use of forward chaining. The system works with input information supplied by the user coupled with knowledge stored in the knowledge base, to draw conclusions or recommendations. The developed system MCKBS overall comprises of more than 800 production rules of IF-THEN variety. A sample of production rules incorporated in the knowledge base of proposed system is given in Table 1.

The user initially loads the system by using graphical user interface (GUI). Proposed system automatically recalls data file labeled as FE.DAT which is generated during execution of feature extraction system. The system also invites the user to enter part data information such as sheet material and production quantity through GUI. The system stores these part data in a data file labeled as PD.DAT. Thereafter, the system checks various design features of sheet metal part from manufacturability point of view. If any design feature(s) of part, such as size of holes, distance between hole(s) and strip edge, distance between two holes, size of notch(es), corner radius, bend angle, bend radius, bend width, size and position of hole/slot, and direction of bend (in case of bending parts), thickness ratio, height ratio, draw radii, draw ratio, etc. (in case of deep drawn parts) is/are not in accordance to the good design practice, the system suggests the user for necessary design modifications. Lastly, the system displays advices for necessary scrap web allowance for manufacturing sheet metal part and stores this output in a data file labeled as SWA.DAT.

Table 1 Production rules included in the system MCKBS

S. No.	IF	THEN
1	Width of blank < 1.5 times sheet thickness	Set minimum width of blank = 1.5 times sheet thickness
2	Length of blank > 5.0 times of width of blank	Set maximum length of blank = 5.0 times of width of blank
3	Width of recesses or slots or projections along blank profile ≥ 1.2 mm	Accept width of recesses or slots or projections
4	Sheet material = Tin/Copper/Brass/Stainless steel/Aluminum; and Design feature = Circular hole; and $0.5 \text{ mm} \leq \text{minimum hole diameter} \leq 1.3$ times of sheet thickness	Accept the diameter of circular hole
6	Minimum distance between two holes on sheet metal part in mm ≥ 2.0 times of sheet thickness	Accept the minimum spacing between two holes on sheet metal part
7	Design feature = Rectangular notch; and Width of rectangular notch in mm ≥ 1.5 times of sheet thickness	Accept the width of rectangular notch
8	Design feature = Rectangular notch; and Length of rectangular notch in mm ≥ 5.0 times of sheet thickness	Accept the length of rectangular notch
9	Minimum internal or external corner radius on sheet metal part in mm ≥ 0.9 times of sheet thickness	Accept the corner radius on sheet metal part
10	Minimum distance of edge to hole in mm < 2.0 times of sheet thickness	Set minimum distance of edge to hole = 2.0 times of sheet thickness
11	Part material = Steel annealed; and Bend radius \leq two times of sheet thickness; and $0^\circ < \text{Angle between bend axis and grain direction} \leq 45^\circ$; and $0^\circ < \text{Bend angle} \leq 135^\circ$	Accept the bend radius
12	Part material = Steel annealed; and Bend radius \leq two times of sheet thickness; and $0^\circ < \text{Angle between bend axis and grain direction} \leq 45^\circ$; and $135^\circ < \text{Bend angle} \leq 180^\circ$	Set the bend radius \geq two times of sheet thickness, 'OR' Set the bend angle < 135°, 'OR' Set angle between bend axis and grain direction > 45°
13	Part material = Steel annealed; and bend radius \leq two times of sheet thickness; and $45^\circ < \text{Angle between bend axis and grain direction} \leq 90^\circ$; and $90^\circ < \text{Bend angle} \leq 180^\circ$	Accept the bend radius
14	Part material = Steel annealed; and two times of sheet thickness < Bend Radius \leq four times of sheet thickness; and $0^\circ < \text{Angle between bend axis and grain direction} \leq 45^\circ$; and $0^\circ < \text{Bend angle} \leq 180^\circ$	Accept the bend radius

(continued)

Table 1 (continued)

S. No.	IF	THEN
15	Part material = Steel annealed; and Two times of sheet thickness < Bend radius \leq four times of sheet thickness; and $45^\circ <$ angle between bend axis and grain direction $\leq 90^\circ$; and $0^\circ <$ Bend angle $\leq 180^\circ$	Accept the bend radius
16	Part material = steel annealed; and Bend Radius > four times of sheet thickness; and $45^\circ <$ angle between bend axis and grain direction $\leq 90^\circ$; and $0^\circ <$ Bend angle $\leq 180^\circ$	Accept the bend radius
17	Part material = Steel Annealed; and Minimum bend radius < 0.5 times of sheet thickness	Set the minimum bend radius = 0.5 times of sheet thickness
18	Part material = Cu ETP; and Minimum bend Radius < 0.25 times of sheet thickness	Set the minimum bend radius = 0.25 times of sheet thickness
19	Ratio of flange diameter to cup diameter < 1.1; and $0.002 \leq$ Ratio of sheet thickness to blank diameter < 0.005	Set the ratio of cup height to cup diameter ≤ 0.60
20	Ratio of flange diameter to cup diameter < 1.1; and $0.005 \leq$ Ratio of sheet thickness to blank diameter < 0.01	Set the ratio of cup height to cup diameter ≤ 0.68
21	$1.1 \leq$ Ratio of flange diameter to cup diameter < 1.3; and $0.01 \leq$ Ratio of sheet thickness to blank diameter < 0.015	Set the ratio of cup height to cup diameter ≤ 0.70
22	$1.3 \leq$ Ratio of flange diameter to cup diameter < 1.5; and $0.0006 \leq$ Ratio of sheet thickness to blank diameter < 0.002	Set the ratio of cup height to cup diameter ≤ 0.40
23	$1.5 \leq$ Ratio of flange diameter to cup diameter < 1.8; and Ratio of sheet thickness to blank diameter > 0.015	Set the ratio of cup height to cup diameter ≤ 0.56
24	Sheet material = Extra deep drawing steel; and $0.0008 \leq$ Ratio of sheet thickness to blank diameter < 0.0015; and Draw stage = First	Set limiting draw rate ≤ 0.63
25	Sheet material = Extra deep drawing steel; and $0.0008 \leq$ Ratio of sheet thickness to blank diameter < 0.0015; and Draw stage = Second	Set limiting draw rate ≤ 0.82
26	Sheet material = Extra deep drawing steel; and $0.0008 \leq$ Ratio of sheet thickness to blank diameter < 0.0015; and Draw stage = Third	Set limiting draw rate ≤ 0.84

(continued)

Table 1 (continued)

S. No.	IF	THEN
27	Sheet material = Extra deep drawing steel; and $0.0015 \leq$ Ratio of sheet thickness to blank diameter < 0.0030 ; and Draw stage = First	Set limiting draw rate ≤ 0.60
28	Sheet material = Extra deep drawing steel; and $0.0015 \leq$ Ratio of sheet thickness to blank diameter < 0.0030 ; and Draw stage = Second	Set limiting draw rate ≤ 0.80
29	Sheet material = Extra deep drawing steel; and $0.0015 \leq$ Ratio of sheet thickness to blank diameter < 0.0030 ; and Draw stage = Third	Set limiting draw rate ≤ 0.82
30	Sheet material = Extra deep drawing steel; and $0.0030 \leq$ Ratio of sheet thickness to blank diameter < 0.0060 ; and Draw stage = First	Set limiting draw rate ≤ 0.58
31	Sheet material = Extra deep drawing steel; and $0.0030 \leq$ Ratio of sheet thickness to blank diameter < 0.0060 ; and Draw stage = Fifth	Set limiting draw rate ≤ 0.86
32	Sheet material = Extra deep drawing steel; and $0.015 \leq$ Ratio of sheet thickness to blank diameter < 0.020 ; and Draw stage = Second	Set limiting draw rate ≤ 0.75
33	Cup geometry = Cylindrical; and $0.75 <$ Height to diameter ratio ≥ 1.50 ; and Number of drawing stages = 2	Set percentage reduction for First draw = 40 %; and Second draw = 25 %
34	Cup geometry = Cylindrical; and $0.75 <$ Height to diameter ratio ≥ 1.50 ; and Number of drawing stages = 3	Set percentage reduction for First draw = 40 %; Second draw = 25 %; and Third draw = 15 %
35	Cup geometry = Cylindrical; and $0.75 <$ Height to diameter ratio ≥ 1.50 ; and Number of drawing stages = 4	Set percentage reduction for First draw = 40 %; Second draw = 25 %; Third draw = 15 %; and Fourth draw = 10 %
36	Sheet material = Extra deep drawing steel; and Ratio of flange diameter to cup diameter ≤ 1.1	$0.0006 \leq$ Set the thickness ratio > 0.02
37	Sheet material = Extra deep drawing steel; and $1.1 <$ Ratio of flange diameter to cup diameter ≤ 1.3	$0.002 \leq$ Set the thickness ratio > 0.005

(continued)

Table 1 (continued)

S. No.	IF	THEN
38	Product size (maximum length/diameter/width) in mm > 25.0 mm; and Product size (maximum length/diameter/width) in mm \leq 75.0 mm; and Sheet thickness in mm < 1.5; and Shape of product edge = Straight or parallel edge	Set minimum scrap web allowance in mm = 1.5 times of sheet thickness
39	Product size (maximum length/diameter/width) in mm > 75.0 mm; and Product size (maximum length/diameter/width) in mm \leq 150.0 mm; and Sheet thickness in mm < 1.5; and Shape of product edge = Straight or parallel edge	Set minimum scrap web allowance in mm = 1.6
40	Product size in mm (maximum diameter/length/width) \leq 25, and Sheet thickness \geq 1.2 mm, and Shape of product edge = curved	Set scrap web allowance in mm = sheet thickness
41	Product size in mm (maximum diameter/length/width) \leq 25 and Sheet thickness < 1.2 mm, and Shape of product edge = curved	Set minimum scrap web allowance in mm = 1.2
42	25 < Product size in mm (maximum diameter/length/width) \leq 75, and Sheet thickness \geq 1.3 mm and Shape of product edge = curved	Set scrap web allowance in mm = 1.25 times of sheet thickness
43	25 < Product size in mm (maximum of diameter, length & width) \leq 75, and Sheet thickness < 1.3 mm, and Shape of product edge = curved	Set minimum scrap web allowance in mm = 1.6
44	250 < Product size in mm (maximum diameter/length/width) \leq 400, and Sheet thickness \geq 2.3 mm, and Shape of product edge = curved	Set scrap web allowance in mm = 1.75 times of sheet thickness

5 Validation of the Proposed Systems FE and MCKBS

The proposed systems have been tested on various types of sheet metal parts. The output generated by the systems FE and MCKBS for three industrial sheet metal parts (Figs. 6, 7 and 8) taken from sheet metal industries namely M/s Indo-German Tool Room, Aurangabad, India, M/s D. D. Engineering Pvt. Ltd., Pune, India, and M/s Kochar Agro Industries Pvt. Ltd. Faridabad, India respectively are depicted in Figs. 9, 10, 11, 12, 13, 14, 15 and 16. The features extracted automatically by the system FE are verified from the CAD drawings of example sheet metal parts. Also, the recommendations/expert advices imparted by the system MCKBS are found to be reasonable and very similar to those actually used in the said industries for the example parts.

Sheet material = Stainless Steel [AISI 1090]

Sheet thickness = 0.5mm

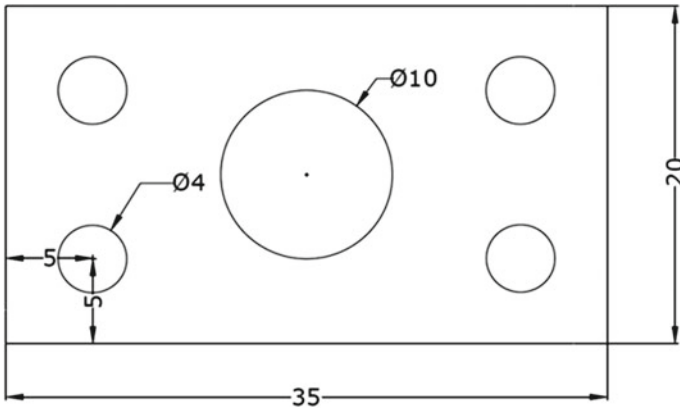


Fig. 6 Example part 1 (All dimensions are in mm) (M/s Indo-German Tool Room, Aurangabad, India)

Sheet material = Stainless Steel [AISI 1090]

Sheet thickness = 0.8mm

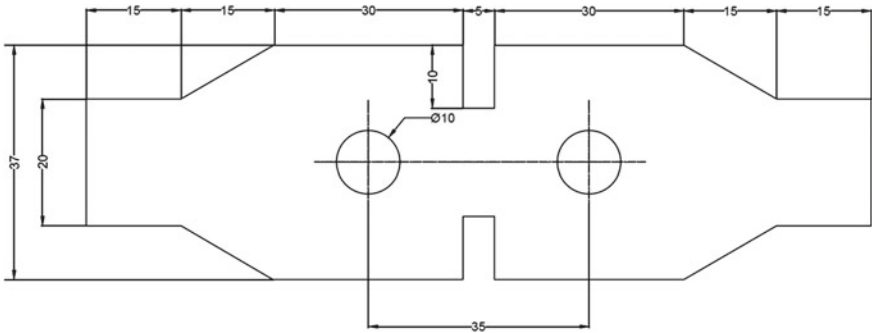
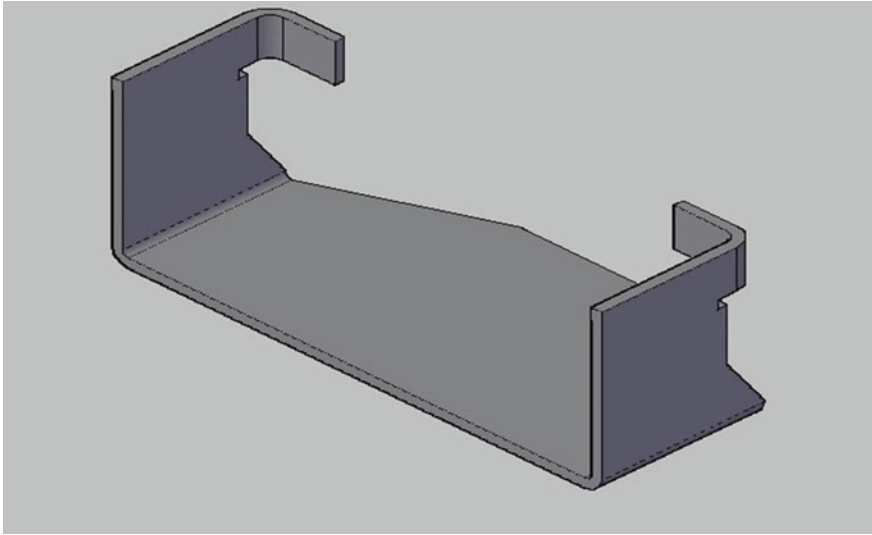
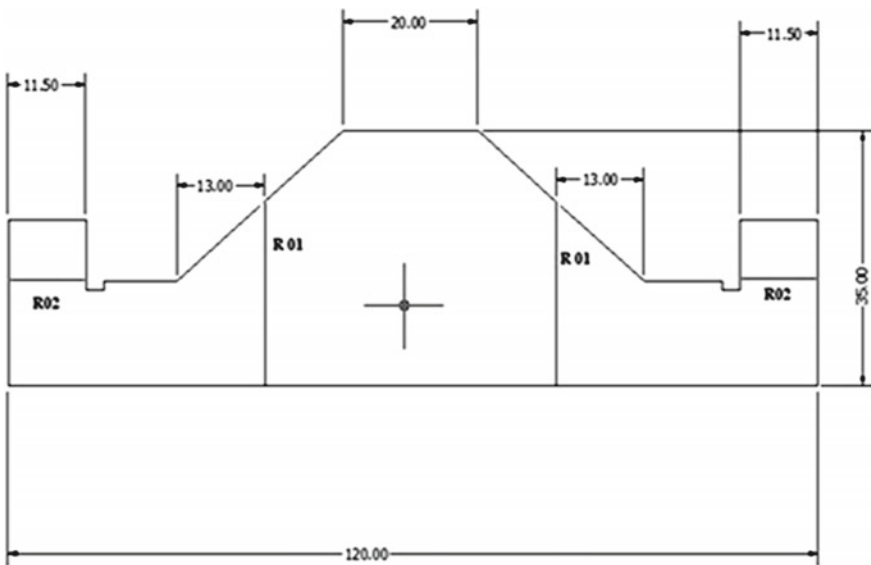


Fig. 7 Example part 2 (All dimensions are in mm) (M/s D. D. Engineering Pvt. Ltd., Pune, India)



(a) 3-D View



Material = Low Carbon Steel Hardened
Sheet thickness = 1.5 mm

(b) 2-D View

Fig. 8 Example part 3 (All dimensions are in mm) (M/S Kochar Agro Industries Pvt. Ltd. Faridabad, India)

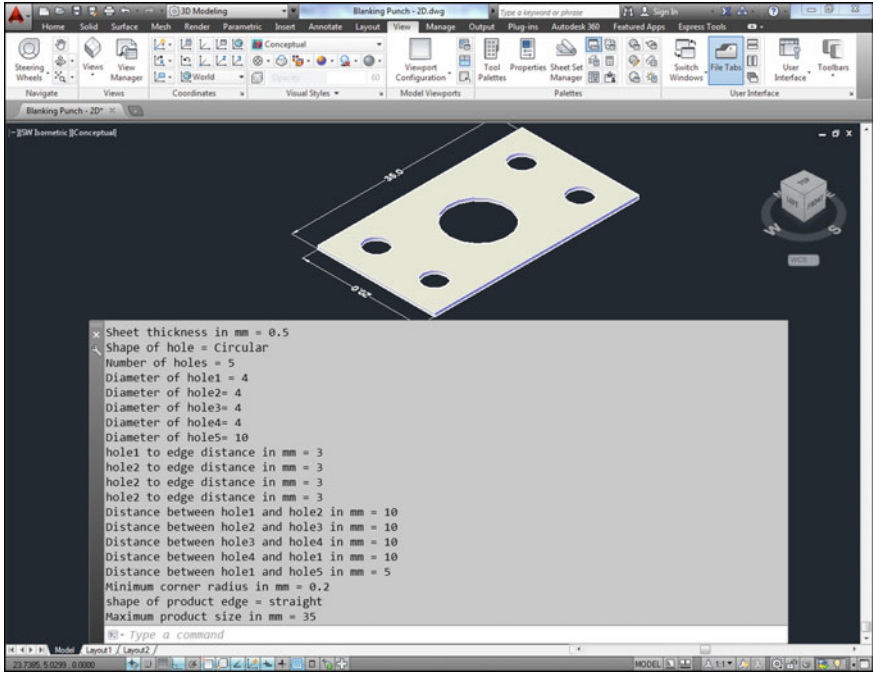


Fig. 9 Output of system FE for example part 1

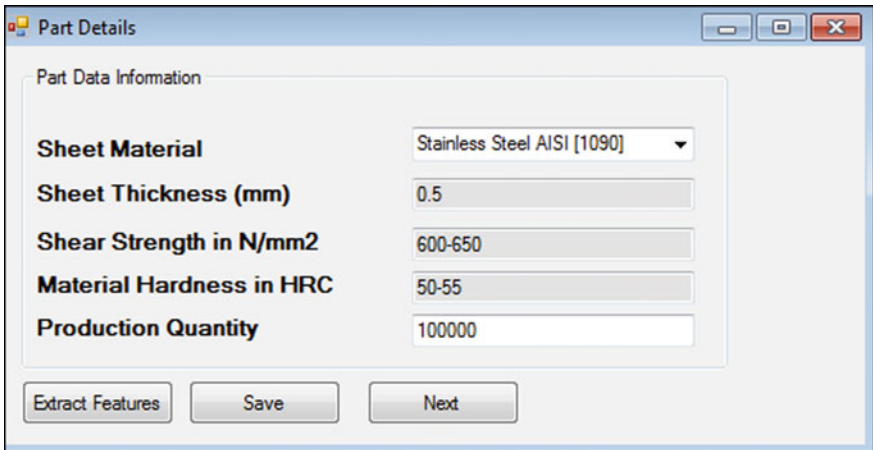


Fig. 10 Input data for MCKBS for example part 1

Hole on part		
Shape of hole	<input type="text" value="Circular"/>	
Number of hole	<input type="text" value="5"/>	
Diameter of smallest holes in mm	<input type="text" value="4"/>	
Minimum distance from edge of hole to edge of sheet metal part in mm	<input type="text" value="3"/>	
Minimum spacing between two hole of sheet metal part in mm	<input type="text" value="5"/>	
Notch		
Type of notch present on sheet metal part	<input type="text"/>	
Width of notch in mm	<input type="text"/>	
Radius of notch in mm	<input type="text"/>	
Length of notch in mm	<input type="text"/>	
Corner Radius		
Minimum internal or external corner radius of sheet metal part in mm	<input type="text" value="0.5"/>	
Scrap Web Allowance		
Select shape of product edge	<input type="text" value="Straight"/>	
Enter the product size in mm i.e. maximum dimension between diameter,length or width	<input type="text" value="35"/>	
<input type="button" value="Extract Features"/>	<input type="button" value="Save"/>	<input type="button" value="Generate Advice"/>

Expert Advice

- Accept the diameter of circular hole
- Accept the distance from edge of hole to edge of part
- Accept the minimum spacing between two holes
- Accept the corner radius on sheet metal part
- Set minimum scrap web allowance in mm = 0.75

Fig. 11 Output of MCKBS for example part 1

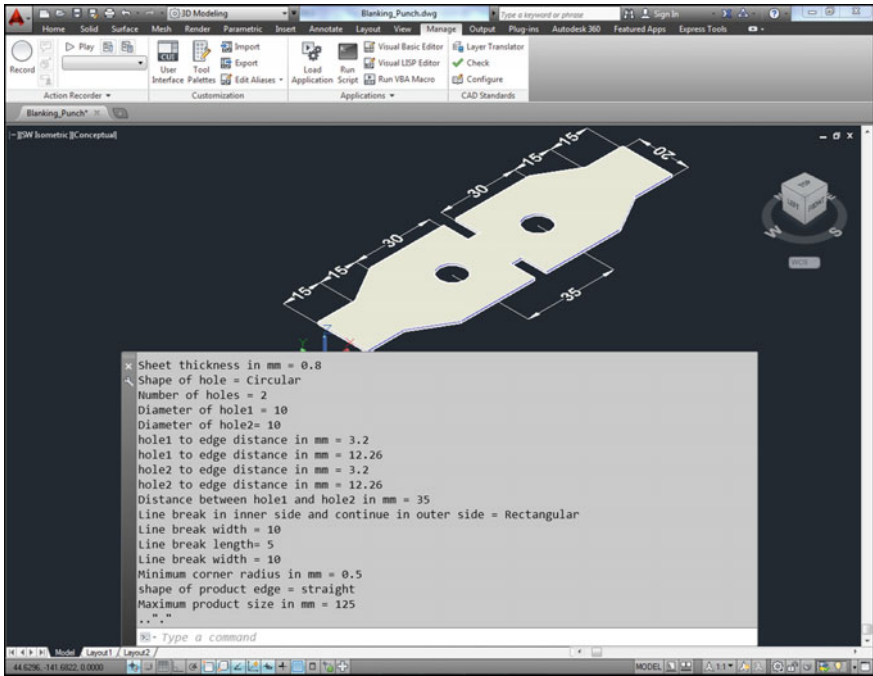


Fig. 12 Output of system FE for example part 2

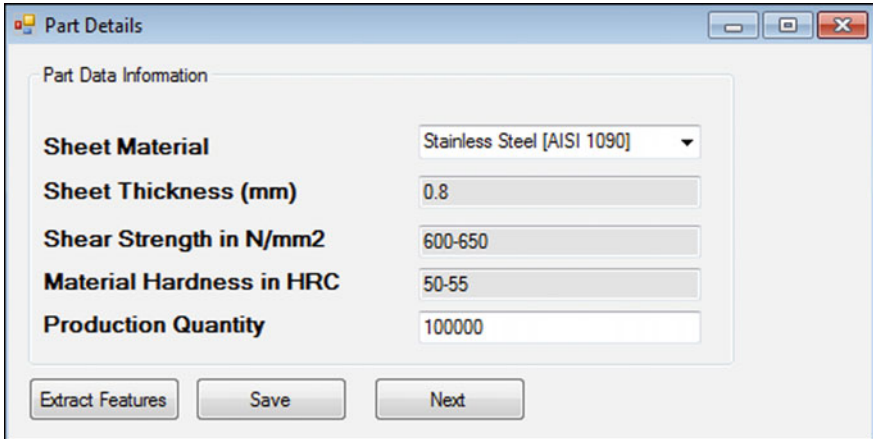


Fig. 13 Input data for MCKBS for example part 2

Hole on part	
Shape of hole	<input type="text" value="Circular"/>
Number of hole	<input type="text" value="2"/>
Diameter of smallest holes in mm	<input type="text" value="10"/>
Minimum distance from edge of hole to edge of sheet metal part in mm	<input type="text" value="3.2"/>
Minimum spacing between two hole of sheet metal part in mm	<input type="text" value="35"/>
Notch	
Type of notch present on sheet metal part	<input type="text" value="Rectangular"/>
Width of notch in mm	<input type="text" value="5"/>
Radius of notch in mm	<input type="text" value=""/>
Length of notch in mm	<input type="text" value="10"/>
Corner Radius	
Minimum internal or external corner radius of sheet metal part in mm	<input type="text" value="0.5"/>
Scrap Web Allowance	
Select shape of product edge	<input type="text" value="Straight"/>
Enter the product size in mm i.e. maximum dimension between diameter,length or width	<input type="text" value="125"/>
<input type="button" value="Extract Features"/> <input type="button" value="Save"/> <input type="button" value="Generate Advice"/>	

Expert Advice

- Accept the diameter of circular hole
- Accept the distance from edge of hole to edge of part
- Accept the width of notch
- Accept the length of notch
- Accept the minimum spacing between two holes
- Accept the corner radius on sheet metal part
- Set minimum scrap web allowance in mm = 1.6

Fig. 14 Output of MCKBS for example part 2

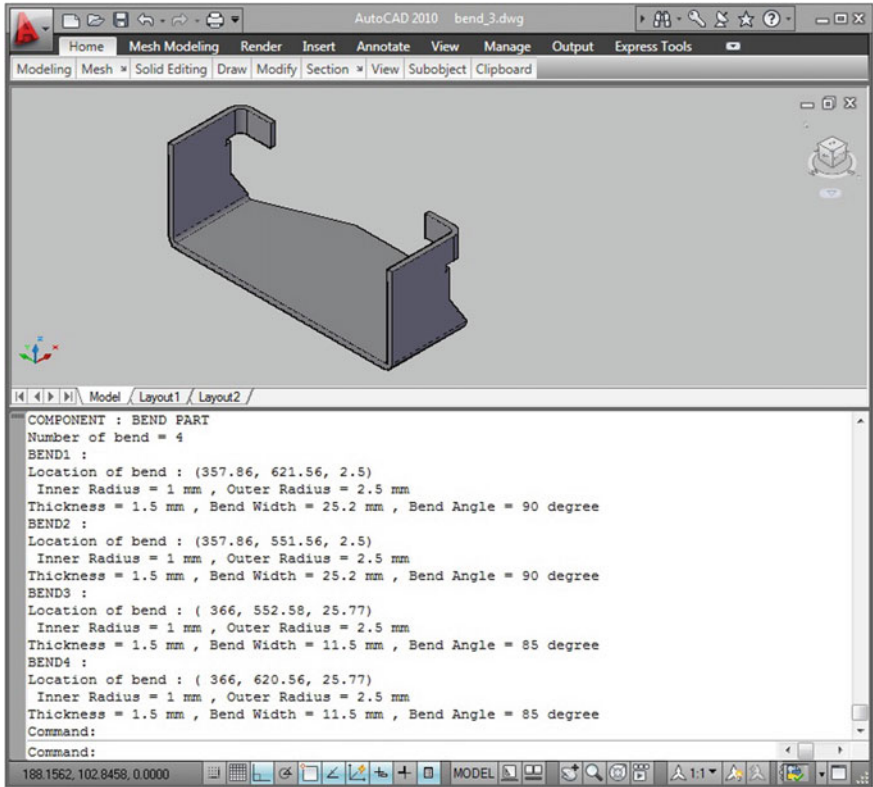
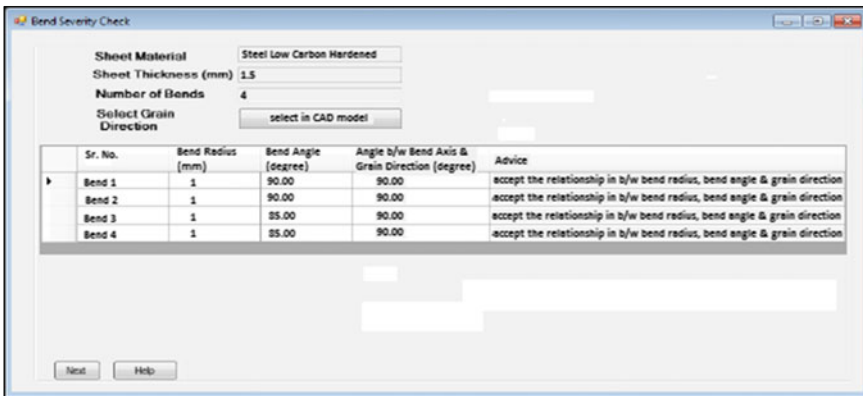


Fig. 15 Output of system FE for example part 3



(a) Check for bend radius



(b) Check for bend severity

Fig. 16 Output of MCKBS for example part 3

6 Conclusion

Feature extraction and manufacturability assessment of sheet metal parts are essential requirements for development of knowledge-based system (KBS) for design of press tools. The present chapter described the work involved in development of computer-aided system for feature extraction and a KBS for manufacturability assessment of sheet metal parts. The usefulness of the proposed systems is demonstrated on three sheet metal parts of different industries. The outputs imparted by these systems are stored in different data files, which are further used in design of different types of dies as described in subsequent chapters.

References

- Choi JC, Kim C (2001) A compact and practical CAD/CAM system for the blanking or piercing of irregular shaped-sheet metal products for progressive working. *J Mater Process Technol* 110:36–46
- Emad A, Kamrani A (2006) IGES Standard Protocol for Feature Recognition CAD System. *Theory and Practice, Rapid Prototyping*, pp 25–38
- Farsi M, Arezoo B (2009) Feature recognition and design advisory system for sheet metal components. In: 5th International advanced technologies symposium (IATS'09), Karabuk, Turkey, pp 1–5
- Hussein HMA, Kumar S (2008) Computer aided check on manufacturability of sheet metal parts. In: Proceedings of the international conference on advances in mechanical engineering, December 15–17, 2008, S.V. National Institute of Technology, Surat, India
- Illiev VI, Propov GS, Ivanov M (1989) A system for computer aided technical preparation in the production of plane parts by stamping. *J Mech Work Techno* 18:283–292
- Ismail N, Bakar N, Juri A (2005) Recognition of cylindrical and conical features using edge boundary classification. *Int J Mach Tools Manuf* 45:649–655
- Kashid S, Kumar S (2013) An expert system for manufacturability assessment of sheet metal parts. In: International Conference on Production and Industrial Engineering (CPIE 2013), NIT, Jalandhar, India, 23–31 March, 2013, pp 58–62
- Kumar S (2011) AI applications to metal stamping die design, *Artificial intelligence: approaches, tools and applications*. Nova Science Publishers Inc., New York, pp 71–95
- Kumar S, Singh R (2011) An automated design system for progressive dies. *Expert Syst Appl* 38:4482–4489
- Kumar S, Singh R (2004) A low cost knowledge base system framework for progressive die design. *J Mater Process Technol* 153–154:958–964
- Kumar S, Singh R, Sekhon GS (2006) CCKBS: A component check knowledge base system for accessing manufacturability of sheet metal parts. *J Mater Process Technol* 172(1):64–69
- Lazaro DS, Engquist DT, Edwards DB (1993) An intelligent design and manufacturability system for sheet metal parts. *Concurrent Eng Res Applica* 1:117–123
- Lee RS, Chuang LC, Yu TT, Wu MT (1995) Development of an assessment system for sheet metal forming. In: Proceedings of the international conference on precision engineering 1995 (2nd ICMT) 'trends and innovations in precision manufacturing technologies, 22–24 Nov 1995, Singapore, pp 515–518
- Liu Z, Li J, Wang J, Li C, Xiao X (2003) Automatically extracting sheet-metal features from solid model. *J Zhejiang Univ Sci* 5:1456–1465
- Makinouchi A (1996) Sheet metal forming simulation in industry. *J Mater Process Technol* 60:19–26
- Meeran S, Pratt MJ (1993) Automated feature recognition from 2-D drawings. *Comput Aided Des* 25:7–17
- Meerkamm H (1995) Product modeling: a prerequisite for effective product development. *Proceeding of Product Modeler*. University of Erlangen, Erlangen, pp 25–47
- Nakahara S, Toshio K, Tamura K, Asuke F, Soda C, Nakamura T (1978) Computer aided progressive die design. In: Proceedings of the 19th machine tool design research conference, London, pp 171–176
- Naranje V, Kumar S (2011) A knowledge based system for manufacturability assessment of deep drawn sheet metal parts. *J Key Eng Mater* 473:749–756
- Naranje V, Kumar S (2014) A knowledge based system for automated design of deep drawing die for axisymmetric parts. *Expert Syst Appl* 41(4):1419–1431
- Prasad YKDV, Somasundaram S (1992) CADDs: An automated die design system for sheet metal blanking. *Comput Control Eng J* 3:185–191
- Radhakrishnan R, Amsalu A, Kamran M, Nnaji BO (1996) Design rule checker for sheet metal parts using medial axis transforms and geometric reasoning. *J Manuf Syst* 15:179–189

- Ramana KV, Rao PVM (2005) Automated manufacturability evaluation system for sheet metal components in mass production. *Int J Prod Res* 43:3889–3913
- Rameshbabu V, Shunmugam M (2009) Hybrid feature recognition method for setup planning from STEP AP-203. *Robo Comp Integr Manuf* 25:393–408
- Shah JJ, Mantyla M (1995) Parametric and feature-based CAD/CAM. Wiley-Interscience Publication, USA
- Srinivasakumar SM, Lin L (1992) Ruled based automatic part feature extraction and recognition from CAD data. *Comput Ind Eng* 22(1):49–62
- Subrahmanyam S, Wozny M (1995) An overview of automatic feature recognition techniques for computer-aided process planning. *Comput Ind* 26:1–21
- Suh NP (1988) Basic concepts in design for producibility. *CIRP Ann Manuf Technol* 37:559–567
- Sunil V, Agarwal R, Pande S (2010) An approach to recognize interacting features from B-Rep CAD models of prismatic machined parts using a hybrid (graph and rule based) technique. *Comput Ind* 61:686–701
- Sunil V, Pande S (2008) Automatic recognition of features from freeform surface CAD models. *Comput Aided Des* 40:502–517
- Tan CF, Ismail N, Ranjit SSS, Kher VK (2013) Feature recognition system for rotational features. *J Appl Sci*. doi:[10.3923/jas.2013.1-6](https://doi.org/10.3923/jas.2013.1-6)
- Tang DB, Zheng L, Zhizhong L, Chin K (2001) An intelligent feature based design for stamping system. *Int J Manuf Techno* 18:193–200
- Wang CH, Bourne DA (1997) Design and manufacturing of sheet metal parts using features to aid process planning and resolve manufacturability problems. *Robo Comput Integr Manuf* 13:281–294
- Wang D, Yan G, Lei Y, Zhang J (2012) A retrieval algorithm of sheet metal parts based on relationships of features. *Chinese J Aero* 25:453–472
- Wierda LS (1991) Linking design, process planning and cost information by feature-based modelling. *J Eng Des* 12:3–19
- Yeh S, Kamran M, Terry Jules ME, Naji BO (1996) A Design advisor for sheet metal fabrication. *IIE Transactions (Insti Indust Eng)* 28:1–10
- Ying DN (1986) CPDDMS—An integrated CAD/CAM system for die equipment design and manufacturing applications. In: *Proceedings of 2nd international conference on computer aided production techniques*, pp 363–370
- Zhou X, Qiu Y, Hua G, Wang H, Ruan X (2007) A feasible approach to the integration of CAD and CAPP. *Comput Aided Des* 39:324–338